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Forestland connectivity in Romania—Implications for policy and management

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ABSTRACT

Forest policies and management rules imposed on forests in Romania provide favourable habitat conditions for many species across forest landscapes. This is empirically proven by the high biodiversity of the Carpathians and their surroundings. However, they do not explicitly address the spatial arrangement of forest patches across landscapes. Therefore, assessment of the connectivity (inside tracts of continuous forest – i.e. intrapatch connectivity – and also among spatially separate patches – i.e. interpatch connectivity) is important. To analyze this, the CORINE Land Cover data set (2012) available for Romania was used. Forest patches were classified into three size categories considered to ensure survival of tree populations on short term, medium and long term: Interconnectivity Nodes (IN: 1,5 to 14,9 ha, minimum 30 m width), Habitat Islands (HI: 15,0 ha and 499,0 ha, minimum 100 m width) and Habitat Continuum (HC: over 500 ha with a minimum 200 m width) respectively. The connectivity of each patch to others around it was assessed for a maximum threshold distance of 1 km. Further connectivity was classified in terms of its strength (depending on the size category to which a patch is connected) and quality (size and structure of a resulting connected cluster). Next, the distributions of the main forest tree species on the various sizes, connectivity strength and quality patches of forest vegetation were assessed. The results showed good connectivity between forest patches, both in terms of intrapatch connectivity (85% of the area was included in the HC class) and interpatch connectivity (92,4% are included in 12 clusters over 10.000 ha; among these the one around Carpathians comprised 86,7% of the total forest area). The main tree species showed good connectivity in general, higher in mountainous areas than at lower elevations (area in Habitat Continuum patches: 97,5% for Norway spruce vs. 63,3% for pedunculate oak; strong connection – 97,8% for Norway spruce vs. 67,2% for pedunculate oak; high quality connectivity – 98,2% for Norway spruce vs. 68,6% for pedunculate oak). These results confirm that management policies and guidelines inherited from the past provide good conditions for connectivity of the main forest tree species and for forests in general. Further enforcement of these practices in the future should ensure the conservation of species across the forested landscapes at national scale and also provide routes for species migration in the context of climate change. However, as a large proportion of forestland is today not state-owned, financial incentives for private owners are a key condition for further acceptance of these policies and ensure these major goals are met.

1. Introduction

Growth and perpetuation of any living organism depends on the habitat conditions available at a certain moment in time. Habitat refers to the range of environments suitable for a particular species (Fischer and Lindenmayer, 2007), a concept similar to the growing space defined for trees by O'Hara as "all resources needed by a tree to exist on a given site" (O'Hara, 1988). Therefore, habitat degradation or loss is linked to species extinction, being recognised as the dominant threat for species on Earth (Sala et al., 2000). However, the same place cannot offer habitat to all living species as some species are able to use growing space in forms or concentrations that are unsuitable for others (Oliver and Larson, 1996). Therefore, certain vegetation structures and site conditions will favour some species and impede the development of others. To ensure the presence of most of the suitable species (a high level of biodiversity), the area must offer a large array of different conditions. Such diverse conditions cannot be met on small areas and therefore, biodiversity maintenance and enhancement should be sought over large tracts of land, or landscapes (large areas ranging from c. 3 km^2–c. 300 km^2 – (Fischer and Lindenmayer, 2007)) which contain a

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mosaic of various ecosystem types and development stages fulfilling the needs of most of the species and thus providing a high biodiversity (Lindenmayer and Franklin, 2002; Tscharntke et al., 2005). As a result, efforts for the conservation of biological diversity have embraced a landscape approach. However, natural landscapes have been shaped by human influences for centuries in most parts of the world (Lienert, 2004), including Romania. The evolution of human society has determined various ways and intensities of natural resources exploitation, some ecosystems being affected than others (e.g. almost half of the temperate broadleaf forests were converted to human dominated uses worldwide (Ehrlich and Pringle, 2008)). Areas suitable for human settlements and agriculture have been overexploited or converted to other uses, while those less suitable for exploitation, like the Carpathian forested landscapes of Europe, were less intensively altered by human activities(Biris and Veen, 2005). As a result, at present, human impacts on structure of the natural landscapes has become a key factor in the analysis and decision making for a sustainable management of natural resources.

However, the presence and mainly the perpetuation of a certain species depend not only on the simple presence of habitat conditions within the landscape. The quantity and quality of the habitat conditions together with their spatial arrangement (the connectivity of habitat patches) in the landscape are determinant factors affecting the fate of that species (Heinrichs et al., 2016). Low quantity of good habitat conditions provides resources for existence of small populations. A similar effect is expected in cases of low quality or degraded habitat (even if on larger areas) in the landscape. Combined with limited connectivity among the habitat islands (fragmentation), the chances for extinction increase substantially (Heinrichs et al., 2016). Therefore, the main anthropogenic threats to the global biodiversity are the degradation, destruction and fragmentation of habitats (Ehrlich and Pringle, 2008; Knorn et al., 2013).

In Romania, the area occupied by forests has decreased from 80% of its territory in the Neolithic period to only 40% by the end of the nineteenth century and to 28% in 1940, a percentage which has remained relatively stable up to present (Veen et al., 2010). The present 6951 million ha of forest and other wooded land reported in 2015, represents 30,2% of the national territory, ranking the country in Europe on the 12th position (in terms of area) and on the 32nd position in terms of cover percentage (FAO and EFI, 2015) (Fig. 1).

The most affected areas by human activities in Romania were in the lowlands, where forested areas were converted to human settlements and agricultural lands (at present only 8% of the forestland is located in the plains, 27% in the hills and the remaining 65% is in the mountains – (Abrudan et al., 2009)). Therefore, forest ecosystems and their associated plants and animal species were historically more impacted at lower elevations than in the higher mountainous areas of the country. Moreover, recent changes in land ownership and the tendency for developing large infrastructure (highways, industrial and human settlements, touristic facilities) are increasing the probability for important changes in habitat conditions, including degradation, destruction and fragmentation. Restitution in the recent decades of a large proportion of forestland to former owners in the context of improper law enforcement capacity (Abrudan et al., 2009) has led to improper management especially on small ownerships. On such lands, inefficient state control and the lack of financial incentives for sustainable management combined with immediate economic benefits of small private owners (individuals) has led to the illegal logging of around 300.000 ha (The World Bank, 2000). Moreover, forest vegetation installed on agricultural lands was often cleared for the reclamation of mountainous pastures. Such changes have raised concerns about forest management sustainability at national level and has even misled some authors who claimed that forest management has shifted from extensive, selective logging to intensive clearcutting (Mikoláš et al., 2015). Moreover, recent studies on the connectivity inside the Natura 2000 network at European Union (EU) level (Estreguil et al., 2013) showed that despite of the large size of sites and total area included in Natura 2000 in Romania, (22,6% of the national territory), the network is not among the top connected networks at EU level.

Despite all these changes and the relatively low percentage of forest cover, Romania still harbours a very high species biodiversity compared to most of Western Europe. This diversity distributed across the entire country and not only in protected areas must be linked to the long-term land use policies and makes it worth of investigation. In terms of forest dwelling species, the legal context of forests and forestry, still tightly regulated by the state regardless of lands ownership (Stancioiu et al., 2010), produces diverse habitat conditions (fulfilling the growing space needs for diverse species) across forested landscapes due to the following provisions:

– through management, stand species composition must resemble the natural forest type (naturally occurring tree species must be

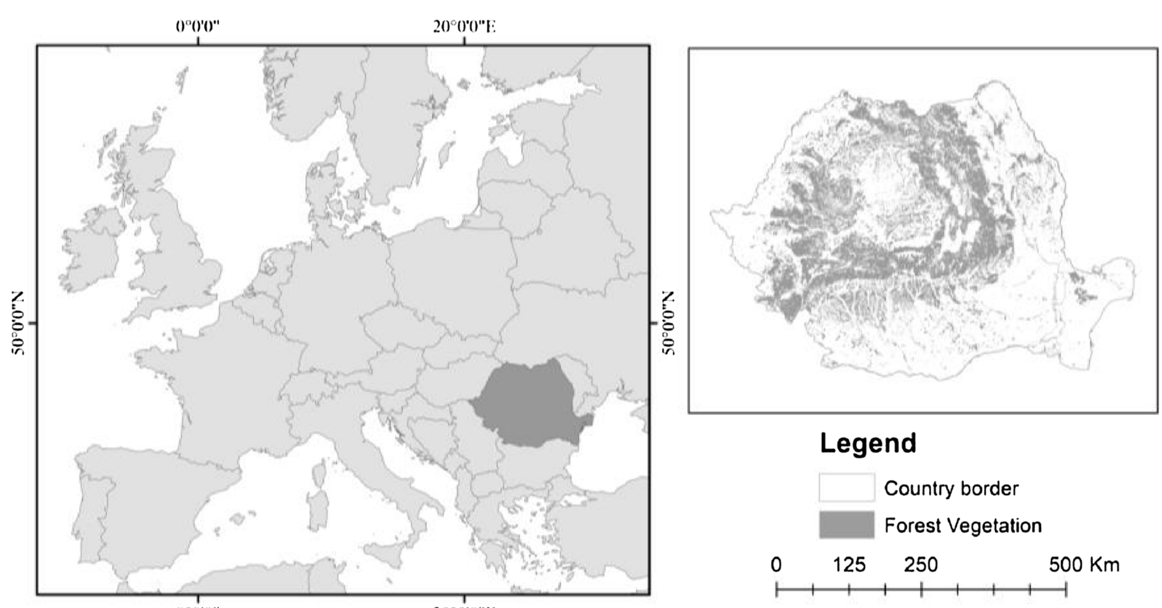

Fig. 1. Romania – geographical location and forest cover across the country.

maintained) (Romanian Parliament, 2008),
- high forest system (regeneration from seed and managed for long rotations) is mandatory with a regeneration cutting age exceeding the maturity of stands (the rotation is usually over 100 years). Coppice is restricted to poplar and willow stands and black locust plantations (Romanian Parliament, 2008),
- natural regeneration installed by repeated cuttings gradually removing the mature stand is the preferred method for establishment of young stands (Romanian Parliament, 2008),
- type, intensity and frequency of silvicultural operations (tending operations) must mimic the natural development of the stand (less intensive and not very frequent) (Romanian Government, 2000a, 2000b),
- to ensure sustainable management, the forestry rules impose on all forestlands a management for a balanced proportion of all age classes (Romanian Government, 2000a) This is rooted in the Principle of Sustained Yield, proposed by G. L. Hartig in the 18th century (Morgenstern, 2007), and results in a mosaic where all development stages are present at all times offering living conditions to the greatest number of species.
- land-use changes in the case of forests are restricted and controlled by the state which imposes strong compensatory measures (beside high financial payments, a 3 times greater non-forest area, adjacent to the state forestland must be afforested in order to compensate the one subject to land-use change) (Romanian Parliament, 2008).

Taking into account all these rules enforced at the national level on all forests and all types of ownership, the quality and quantity of habitat should not decrease despite the recent changes mentioned before. Although maintenance of native vegetation is not perceived as the only way for ensuring the habitat for biodiversity as some of the species could survive in human modified landscapes (Lindenmayer and Franklin, 2002), natural or close to natural ecosystems are more likely to offer good conditions for most of the species (Fischer and Lindenmayer, 2007). At a coarse scale, the presence of natural forest types (with naturally occurring species) along natural gradients should provide a good matrix for most of the species which are using forests as permanent or transition habitats. However, current forest management rules do not necessarily take into account the connectivity among different forest patches (the spatial arrangements of forest patches across landscapes). In this context, the present study had the following objectives:

1) to assess the effect of the present land use policies on the connectivity of forest patches at national level both in terms of intrapatch connectivity (inside individual patches, determined by their individual area) and interpatch connectivity (among habitat patches, determined by the area resulting from connectivity) (Saura and de la Fuente, 2017)
2) to assess the effect of the present land use policies on the connectivity for the main forest tree species in the country.

2. Materials and methods

2.1. Defining forest size classes

To assess the quantity and quality of forest habitats, certain population size thresholds were used. We started from the general 50/500 rule set for minimum viable populations (MVP) (Franklin, 1980) which states that a genetically effective population (N_e) must not be under 50 mature individuals for short term survival (to reduce the likelihood of extinction due to inbreeding) and should have at least 500 mature individuals for long term survival (to keep the evolutionary potential by maintaining a balance between mutation and genetic drift) (Jamieson and Allendorf, 2012).

However, not all individuals in a certain population are mature (reproductive), the sex ratio is not always equal, the number of offspring is neither equal nor constant in time which implies important variations in the population size. Additionally, many other factors can affect the population size and its ability to perpetuate. As a result, the so-called effective population (N_e) is smaller than the actual population (census population – N_c). In many cases, for wildlife species, the ratio N_e/N_c was found to be around 0.1 (Frankham, 1995). Therefore, the minimum thresholds for short and long term survival of a census population would become 500 and 5000 individuals respectively (Traill et al., 2010). Although most of the studies addressed animal species, similar numbers were proposed for plants as well, based on a review on 22 species covering mosses, ferns, dicotyledons, monocotyledons and gymnosperms (Traill et al., 2007).

This particular study, deals with populations of forest trees, which are long living organisms that, once reaching the reproductive stage, produce pollen and seeds regularly and in quite large quantities for long periods of time. We used the 50/500 rule as we set as a limit the presence of at least 50 and 500 mature trees respectively, able to produce pollen and seeds. As a result, for our study, we have set the following thresholds for forest tree populations:

- with minimum 50 adult individuals – small populations where species can survive but at the limit (short term survival, medium to high risk for extinction)
- with minimum 500 adult individuals – medium size populations able to persist on long term (medium to low risk for extinction)
- with minimum 50.000 adult individuals – large populations able to persist on very long term (very low to no extinction risk)

To allow for a spatial analysis, the minimum numbers of individuals were transformed to area thresholds and therefore minimum areas instead of minimum population sizes were set. The size of the minimum area was determined starting from the individual space needed for one mature tree from a certain species. We used the number of such trees per hectare at rotation age (when trees are already mature for many years and the size remains relatively unchanged), in best site conditions (site class 1) where the stand density is the lowest (fewer but larger trees per hectare). The total number per hectare for the main forest tree species in Romania in such site conditions and for a 70% crown cover, ranges from 251 for the shade tolerant Norway spruce (at rotation age of 120 yr.) to 181 for the shade intolerant pedunculate oak (at rotation age of 130 yr.) (Giurgiu and Draghiciu, 2004). As a result, the space for each individual tree in a hectare ranges from 39.84 to 55.24 m^2, resulting (assuming equal spacing) in a distance between the boles of two neighbouring trees of 6.3–7.4 m. As in some cases the number of trees per hectare can be lower (the spacing can be wider and/or crowns could be wider), we used a 10 m distance between neighbouring trees to determine the minimum areas for forest size classification. Setting a higher mean distance between neighbouring trees would ensure a larger area which in turn could possibly host more trees than the minimum number set. Also, many of the site conditions are rather far from being top quality and therefore density (i.e. number of trees per hectare) would be higher on the same area than the minimum number set (50 or 500). Therefore, the minimum size area resulting from our calculations are likely to contain more trees than the minimum number set for the minimum viable populations. In the case of relatively uneven aged structures (a rather rare situation in Romania's forests), the mixture of trees of different age and size would ensure a much larger number of individuals per hectare (larger than the 500/5000 resulting from the N_e/N_c ratio of 0.1).

Furthermore, as in most cases forest stands contain more than one tree species (even those dominated by one species), to accommodate for the presence of at least three different species, for the minimum area calculations, we multiplied the minimum numbers for the population by 3 (resulting in minimum aggregate numbers of 150 and 1500 individuals respectively). In addition, for stability of the ecosystem, a

minimum width limit for the category area was also set.

As a result of these requirements and the above set sizes for populations, two different classes of size areas resulted for the analysis, namely: Interconnectivity Nodes (IN) and Habitat Islands (HI)

The interconnectivity nodes (IN) are the smallest areas where populations can survive but at the limit. Such populations, as defined above, have between 50 and 499 individuals. To accommodate for the situation of mixed stands with 3 species, a minimum number of 150 trees was considered as the minimum threshold for this category. Using the average distance of 10 m between neighbouring trees and assuming an even spacing, the minimum resulting area was 1.5 ha. As the area is very small for a forest, the edge effect can become very important. Therefore, to assess the quality of this category, besides area, a minimum stand width of 30 m (to allow the presence of at least three trees in line) was also considered as a threshold condition. Areas which did not meet the width requirements were discarded from the analysis.

The habitat islands (HI) are areas large enough to ensure persistence of populations on long term at medium extinction risk. Such populations should have 500 individuals or more. Here as well, as forests are made of more than one tree species, instead of 500 individuals, a minimum number of 1500 trees was considered as the threshold for this category (to allow for the presence of 3 different species). Using the same average distance between neighbouring trees we have obtained a minimum area of 15.0 ha for this category. To account for the edge effect, considered to be around 50 m or two times the average height of the temperate forest vegetation (Lefsky, 2010), the minimum width was set to 100 m. Areas that fulfilled the minimum size threshold but did not meet the minimum width requirements were included in the previous category (IN). Furthermore, as only a lower limit was set for this category, it could be inferred that any area larger than 15.0 ha could be at a medium extinction risk, an assumption which cannot be sustained for the very large compact forested areas which occur in the Romanian Carpathians. Therefore, besides these two area categories, we have set a third one, the Habitat Continuum areas (HC), which should be large enough to ensure the stability and resilience of the forest ecosystem for very long time. For this category, the minimum area was considered to be over 500 ha, which is ten times larger than the 50 ha proposed by Korpel as the minimum area for ensuring self-regulating and perpetuation of a temperate forest ecosystem (Korpel, 1995). Such an area, based on the general spacing used so far in the analysis (i.e. 10 m^2 for each individual mature tree), would accommodate for at least 50.000 trees ensuring therefore room for large enough populations of various tree species with very good chances of perpetuation. The minimum width for controlling edge effects was set to 200 m as to ensure a strip of at least 100 m which is completely outside of the 50 m edge effect. Areas that fulfilled the minimum size threshold but did not meet the minimum width requirements are included in the previous categories (IN or HI). As a result of introducing this category, a maximum size of 499 ha was automatically set for HIs (which in turn, based on the spacing used in this study, a maximum population size of around 49.900 individuals).

It should be stressed that a population, from the reproductive success point of view, should be regarded as all individuals from a certain species which have a chance for mating. Therefore, although the above-mentioned category sizes were built mainly based on the viability rule, as long as areas from different categories are spatially close enough to allow for reproductive success, they should be considered as part of the same population. For example, an IN, even if it is too small to ensure perpetuation of the population on long run by itself, as long as it is close enough to other areas (HC, HI or even IN) with individuals of the same species, should be considered as part of the same population (connected to the same population) and decision on the viability and risk should be taken at the larger scale level including all of the connected areas (the entire population and its particular spatial arrangement).

2.2. Identification of size classes at national level

For analysis, the ArcGIS 10.2 for desktop software was used. Information was extracted from the available CORINE Land Cover 2012 dataset (Eionet Network, 2012). The following habitat classes were taken into account: 311 Broad-leaved forest, 312 Coniferous forest, 313 Mixed forest and 324 Transitional woodland/shrub. The last category, even though contains some areas which are not forestland and might be cleared in the future (abandoned meadows and pastures or after disturbances of various origin) was included in the analysis to not lose the areas covered by regeneration cuttings (i.e. with young forests with herbaceous vegetation and/or dispersed solitary trees) and those with forests subject to various levels of degradation caused by natural or anthropogenic disturbances (industrial pollution, and others). This dataset was useful for the analyses performed in this study as it contains a rigorous classification of the land cover categories (Jaffrain, 2017). The 2012 dataset was improved compared to older versions as it incorporated information available at the country level (extracted from existing databases on forests, pastures and other types of land-use). Despite the fact that it does not take into account patches smaller than 25 ha, the CORINE Land Cover dataset was still considered a better option for achieving the study goals compared to other existing products extracted from satellite images based on poor validation data.

Using the above-mentioned habitat classes, the three proposed size categories were determined according to the procedure depicted in Fig. 2.

A limitation of the CLC 2012 data set is the fact that the layers do not contain areas of forest habitats smaller than 25 ha. As a result, INs (with an area of less than 15 ha) and some of the HIs (those less than 25 ha) cannot be identified based only on size. They could only result from the processing of HC and HI polygons for width requirements (Fig. 3).

2.3. Define connectivity threshold

To assess the connectivity of the different forest patches, from the point of view of tree species, the distance between such patches was used. Gene flow either through pollen or seeds could alleviate the negative effects of small size populations (the so-called genetic drift) (Lienert, 2004). Therefore, a distance which allows for genetic exchange between two neighbouring patches was sought. However, gene flow differs between species and even in the case of the same species it varies both in space and time, being influenced by the landscape and other factors such as wind (Lienert, 2004). Although earlier literature (Enescu, 1982; Stanescu, 1984) recommended distances to up 1 km as sufficient in order to ensure the isolation of seed orchards from foreign pollen sources, recent genetic studies have shown that pollen dispersal by wind can reach distances much larger than this limit. For example, Lindgren et al. have found that, in Sweden, *Pinus sylvestris* pollen, lifted by turbulence in the afternoon to elevations of 1000–2000 m, can travel 360 km in 10 h (Lindgren et al., 1995). MacInnis found that pollen can be carried to distances between 5 and 10 km for three conifer species (*Picea mariana*, *Pinus banksiana* and *Abies balsamea*) (MacInnis, 2012). Even more, as uneven canopies favour wind turbulence (Di-Giovanni and Kevan, 1991) and thus pollen uplifting, fragmentation would rather result in increased pollination dispersal distances than hindering gene flow (Ashley, 2010). O'Connell et al. also found that, although most of the seeds and pollen fall near the mother plant, pollen dispersal by wind for *Picea glauca* can reach long distances (up to 3 km) the minimum average dispersal distance being around 620 m (O'Connell et al., 2007). Such long distance dispersal events are playing an important role allowing for colonisation of remote sites and more important they promote gene flow among remote populations and therefore counteract genetic drift (Ellstrand, 1992a, 1992b). Although pollen flow is very important to ensure genetic viability of a population on long term, seed dispersal capacity is also important. Dispersal mechanisms become very

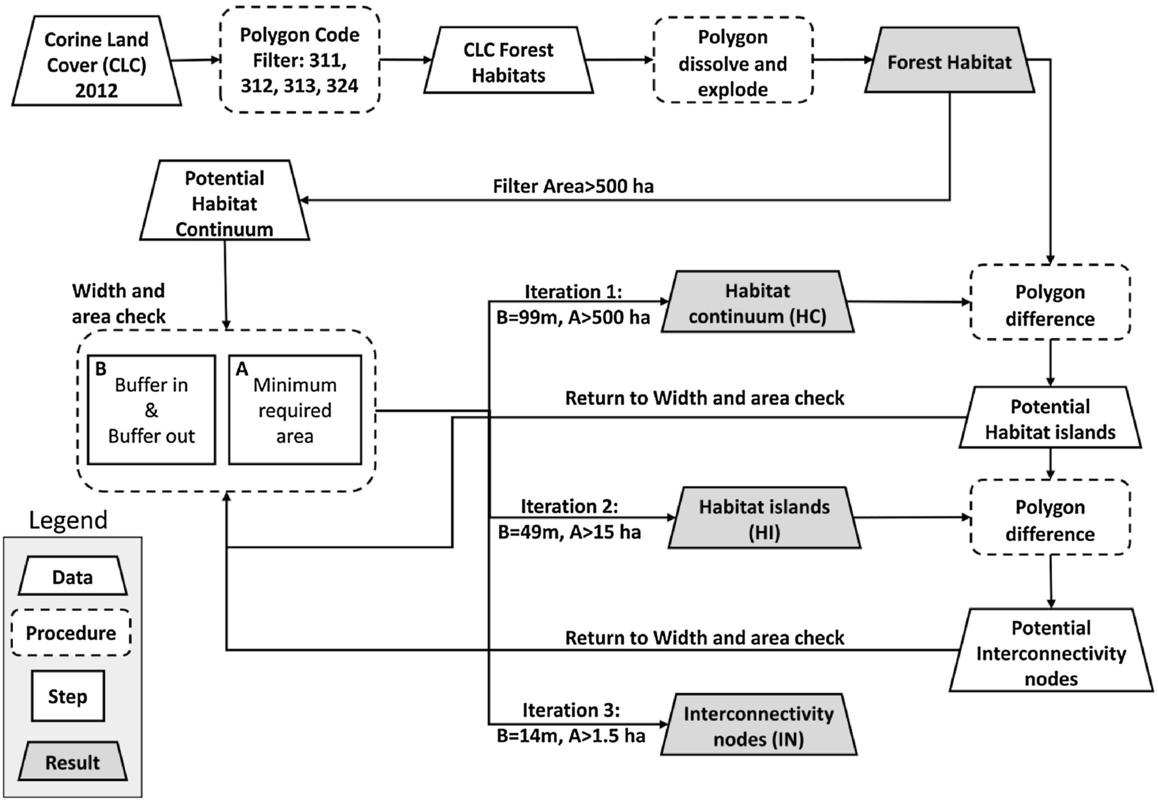

Fig. 2. Workflow for processing the CLC 2012 forest polygons into size categories.

important for colonising former sites where the species has been replaced by others, or where individuals of that species are below maturity age (a common situation in the case of forest tree species) and therefore, the mixture of genetic material based on pollen dispersal from other neighbouring sources might be seriously hindered. As a result, to have a precautionary approach, the shortest distance of the two mechanisms should be used for assessing connectivity. For trees, Vittoz and Engler analyzed the available literature for temperate regions and proposed a range of 400–1500 m for trees as corresponding to the dispersal of 50 and 99% of the seeds through zoochory (i.e. seeds being either gathered for storage by animals, eaten by birds and large vertebrates or accidentally transported by large mammals) (Vittoz and Engler, 2007). Another study on the connectivity and connectedness of Natura 2000 sites in Europe (Opermanis et al., 2012) has proposed that

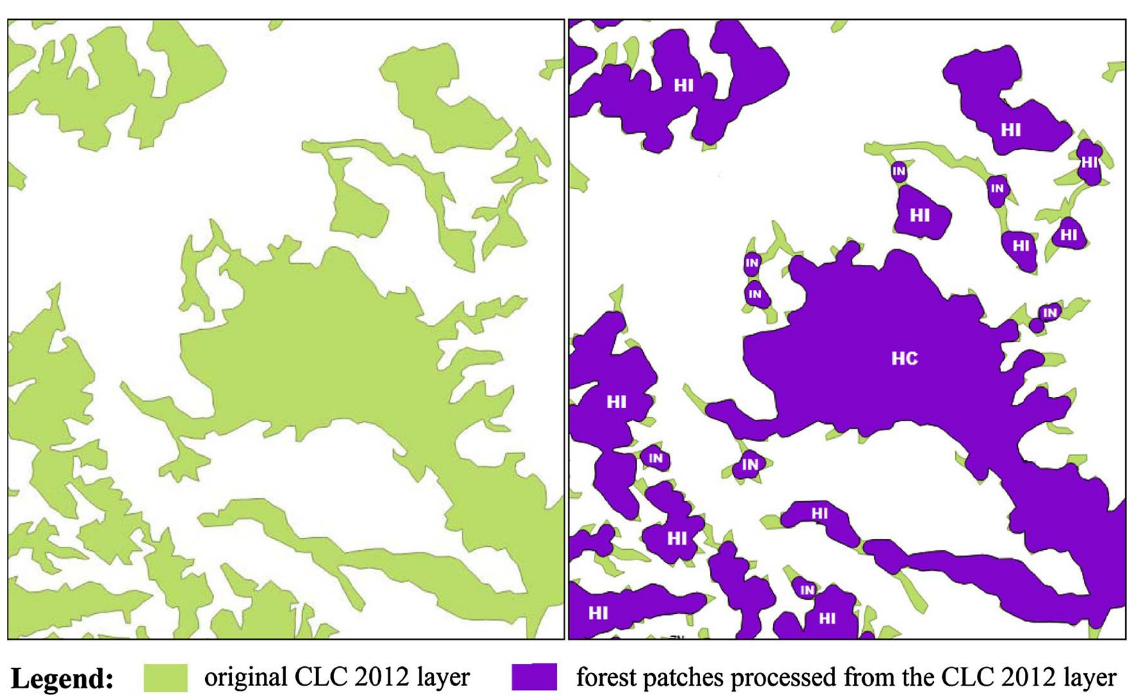

Fig. 3. Habitat islands (HIs) and Interconnectivity nodes (INs) resulting from the width requirements processing of the original CLC 2012 data set.

1000 m would be a fair distance for many animal species to travel between different habitat patches as it reflects the maximum dispersal capacities for many species with limited dispersal abilities.

According the information presented above and taking into account that dominant forest tree species are wind pollinated and seeds are dispersed by both wind and animals, a maximum distance of 1000 m for assessing connectivity was used in this study. This distance was also used in other studies concerning connectivity/fragmentation of forest habitats (Estreguil et al., 2013, 2012). Therefore, forest patches located closer than 1000 m are considered to have good chances for a sufficient gene flow to ensure their connectivity and long-term survival.

2.4. Determine connectivity and define connectivity strength classes

The large number of polygons and mainly the large number of vertex along their perimeter impeded the use of dedicated software such as CONEFOR Sensinode (Saura and Torné, 2009). Connectivity was therefore determined by setting a buffer of 500 m to each category (HC, HI and IN polygons) separately. Three separate buffer layers resulted.

Further, patches of forest located at 1 km apart or closer (buffer areas that overlap or touch each other and imply a distance between patches of less than 2 × 500 m = 1 km) were considered as connected. To check the connectivity between the different size categories (HC/HI/IN), the three separate buffer layers were merged into one layer. Depending on the patch size class, potential connectivity strength was interpreted differently as follows:

- connections to a HC (regardless of the size category) could be strong.
- connections of HIs could be medium
- connections of INs could be weak
- HCs, HIs and INs without any connection would be classified as not connected.

To identify non-connected polygons, we used the ArcGIS function Polygon Neighbours (from Tool Proximity) choosing both 'Include both sides of neighbour relationship' and 'Include area overlaps'. For all polygons without connections to others, the present status was manually changed from strong/medium/weak to not connected.

To eliminate overlapping inside each connectivity category (strong, medium, weak), we used 'Merge' to combine polygons of the connectivity layer into one feature polygon and then 'Explode' to separate the multipart feature polygon into individual feature polygons.

For connected polygons from the three different category layers, overlaps between different connectivity strength levels were detected (e.g. strong over medium, strong over weak and medium over weak). To solve these overlaps, the higher ranked polygon was subtracted from the lower ranked polygon using the 'Erase' tool. A correct topological layer (without overlaps), with all three connectivity categories was obtained. Polygons previously identified as not connected were added to this layer and a new layer resulted, named the Cluster layer.

Further, to identify the most important potential locations where connectivity could be substantially improved with the highest efficiency (where connectivity between important clusters or large patches could be acquired with least effort) on a large scale, five larger buffer widths were also tested: 750 m, 1000 m, 1500 m, 1750 m and 2000 m. These resulted in connectivity distances of 1500 m, 2000 m, 3000 m, 3500 m and 4000 m respectively.

2.5. Determine connectivity quality

On the Cluster layer (including all polygons, connected or not), we analyzed the quality of connectivity for each connected unit (cluster) based on its total area and origin of the cluster (originating from HC/HI/IN). First, all three layers with habitat categories (HC/HI/IN) were merged into one single layer (Habitat Category Layer – HCL). Next, using the 'Intersect' function on the Cluster and HCL layers all polygons from the latter were assigned the ID from the Cluster from which they belonged. The resulting information was analyzed in Microsoft Excel by the 'PivotTable' function establishing for each cluster of connected polygons the number of forest patches inside the cluster and the summed area for each category (HC, HI, IN). Further, based on the area and patch type, each polygon was attributed to one of the following connectivity quality classes:

a Areas with Low Connectivity Quality:
  - very small areas of maximum 50.0 ha, e.g. 10% of a HC or the size of a self-regulating forest ecosystem in the temperate zone (Korpel, 1995), resulting from one unconnected forest patch or from more connected smaller patches
  - connected areas (clusters) of between 50.1 and 500.0 ha of which more than 50% were from INs

b Areas with Medium Connectivity Quality:
  - unconnected polygon of 50.1–500.0 ha
  - connected areas (clusters) of between 50.1 and 500.0 ha of which less than 50% were from INs
  - connected areas (clusters) of between 500.1 and 5000.0 ha of which more than 50% come from HIs and INs

c Areas with High Connectivity Quality:
  - unconnected polygon over 500.1 ha
  - connected areas (clusters) over 500.1 ha of which less than 50% were from HIs and INs

2.6. Distribution and connectivity for main forest tree species

For information on species distribution at the national level, the Forest Vegetation Map from 1997 was used (Donita et al., 1997). This map was realised based upon stand composition information extracted from forest management plans. The analysis was carried out on the GIS version of this map developed in 2006 (LIFE Nature Project, 2006).

The following species/groups were included in the analysis: Norway spruce (*Picea abies*), European beech (*Fagus sylvatica*), sessile oak (*Quercus petraea*), pedunculate oak (*Quercus robur*) and Italian oak (*Quercus frainetto*) and Turkey oak (*Quercus cerris*) grouped together. For each species or group, map codes matching forest types containing that species or group were pooled together to estimate the species range. The selection for each species or group was saved as a separate layer and all polygons were merged by the 'Dissolve' function to obtain maps with the species range distribution. These maps were intersected with the forest size classes map and also with the forest connectivity quality and strength maps. Therefore, a distribution of species range across forest patches classified in terms of their size and connectivity strength and quality was obtained.

3. Results

3.1. Patch size classes

The GIS analysis resulted in a total forest vegetation area at the country level of 7.142.203,87 ha, very close to the 7.046.056,011 ha provided by the National Forest Inventory (INCDS "Marin Dracea," 2016). As shown in Table 1, out of this area, 931 polygons were classified as HC (accounting for 85% of the area), 13.182 as HI (accounting for 13.5% of the area) and 14.958 as IN (accounting for 1.5% of the area). As expected, the variation of polygon area is large, especially for HCs where no maximum limit was set.

3.2. Connectivity and connectivity classes

According to Table 2, around 97% of the forests (28.128 out of 29.071 polygons) were connected to at least another forest around them

Table 1
Cover (ha), count (no.) and proportion (%) of the three forestland size categories. (HC – habitat continuum; HI – habitat islands; IN – interconnectivity nodes; resulting from HC – fragments of HC patches which did not meet the minimum width requirements for the HC category and were classified as HIs or INs (depending on their size and width); resulting from HIs – fragments of HI patches which did not meet the minimum width requirements for HI category and were classified as INs).

Statistics	*HC Area*	*HI Area*		*IN Area*		
		TOTAL	*resulting from HC*	*TOTAL*	*resulting from HC*	*resulting from HI*
Mean	6.517,04	73,24	77,27	7,32	7,16	7,52
Standard Error	1.503,53	0,75	1,42	0,03	0,04	0,04
Median	1.027,42	37,40	35,64	6,49	6,30	6,74
Standard Deviation	45.876,19	86,51	97,75	3,28	3,22	3,35
Minimum	500,76	15,01	15,01	3,14	3,14	3,14
Maximum	890.965,74	499,87	499,87	14,996	14,99	14,996
Sum	6.067.368,65	965.404,09	368.111,79	109.431,13	60.110,94	49.320,19
TOTAL AREA (ha)	7.142.203,87					
Proportion of total area (%)	85,0%	13,5%		1,5%		
Count (no. of patches)	931	13182	4764	14958	8399	6559
TOTAL COUNT (no. of patches)	29.071					
Proportion of total count (%)	3,2%	45,3%		51,5%		

Table 2
Statistics on forest patch connectivity.

Statistics of area (ha)	Polygon status	
	Connected	*Not connected*
Mean	250,29	108,27
Standard Error	50,22	6,64
Median	13,67	41,27
Standard Deviation	8.422,32	203,83
Minimum	3,14	3,20
Maximum	89.0965,74	2.364,63
Sum (ha)	7.040.108,70	102.095,17
Count (no.)	28.128	943
Total area = 7.142.203.87 ha		
Total polygons count = 29.071 units		
% of total area	98,6	1,4
% of total count	96,8	3,2

(in a range of maximum 1 km). They encompassed almost 99% of the total forested area of the country, including forests from 3,14 ha to 890.965,74 ha. Those without any connections (943 polygons, representing 3,2% of the total of 29.071 polygons) ranged from 3.20 ha to 2364,63 ha and covered less than 2% of the total area.

However, not only the existence of connectivity is important but also how much of area is connected in a cluster (the interpatch connectivity). Therefore, the clusters resulting from connections were also important. According to Table 3 a total of 919 clusters resulted out of the 28.128 polygons with connections.

The largest connected area corresponded to the Carpathian Mountains and had 6.103.601,57 ha (comprising 86,7% of the total connected forest area and 85,5% of the entire forestland). Another 11 clusters over 10.000 ha also resulted. These covered 401.170,59 ha and together with the previous one made 92,4% of the total connected forest area at country level (and 91,1% of the entire forestland). Many rather small connected and unconnected patches were interspersed with these large clusters (Fig. 4).

Table 3
Statistics on clusters resulting from connections among forest patches.

Cluster area (ha) and count (no.)	
Mean	7.660,62
Standard Error	6.643,18
Median	166,23
Standard Deviation	201.388,06
Minimum	7,42
Maximum	6.103.601,57
Sum	7.040.108,70
Count (no.)	919

The stepwise increase in buffer width to 750 m, 1000 m, 1500 m, 1750 m and 2000 m (which produced connectivity distances of 1500 m, 2000 m, 3000 m, 3500 m and 4000 m), besides the expected effect of increasing connectivity also showed where and with what efforts the connectivity can be improved at larger scales (details on Figs. 1–6, Appendix in Supplementary material). The most important change, both in terms of spatial connectivity and total cumulated area, would be the connection to the largest cluster (the Carpathian Mountains) obtained for a buffer width of 500 m (Fig. 4 here; Fig. 1 in Appendix in Supplementary material), especially the connection of the other large clusters (i.e. over 10.000 ha, Fig. 4). In terms of spatial connectivity, when the buffer was extended to 750 m (connectivity distance of 1500 m), the Carpathian Mountains cluster became connected to other patches/clusters around it including the two large (i.e. over 10.000 ha) clusters from the north-west of the country (Fig. 2 in Appendix in Supplementary material), After increasing the buffer to 1000 m (connectivity distance of 2000 m), only the cluster from south (over 10.000 ha) connected to the Carpathian cluster. However, the connectivity was advancing in the south-west towards the Danube River adding new smaller patches/clusters (Fig. 3, Appendix in Supplementary material). For a buffer of 1500 m (connectivity distance of 3000 m), the Carpathian cluster became connected to all clusters over 10.000 ha in north-east and east. In addition, connectivity in the central area of the country also increased (Fig. 4, Appendix in Supplementary material). The increase to 1750 m (connectivity distance of 3500 m) did not connect any of the remaining clusters over 10.000 ha. However, the Carpathians cluster expanded towards south and south-west including new areas and connecting to the Danube River (Fig. 5, Appendix in Supplementary material), Finally, the 2000 m buffer width (connectivity distance of 4000 m), connected the remote clusters from south-east connecting most of the forestland (Fig. 6, Appendix in Supplementary material).

In terms of total area of the resulting cluster (Table 1, Appendix in Supplementary material), the largest increases occurred for a buffer of 1500 m (connectivity distance of 3000 m – Fig. 4 in the Appendix in Supplementary material) and 2000 m (connectivity distance of 4000 m – Fig. 6 in the Appendix in Supplementary material) respectively. For the first case, the area connected into the Carpathians cluster became 6.725.151,9 ha (compared to 6.103.601,6 ha for the original buffer of 500 m), the proportion of the entire forestland included in this cluster increasing from 85.5% to 94.2%, while for the second case, the Carpathians cluster reached 7.059.351,1 ha (representing 98.8% of the entire forestland).

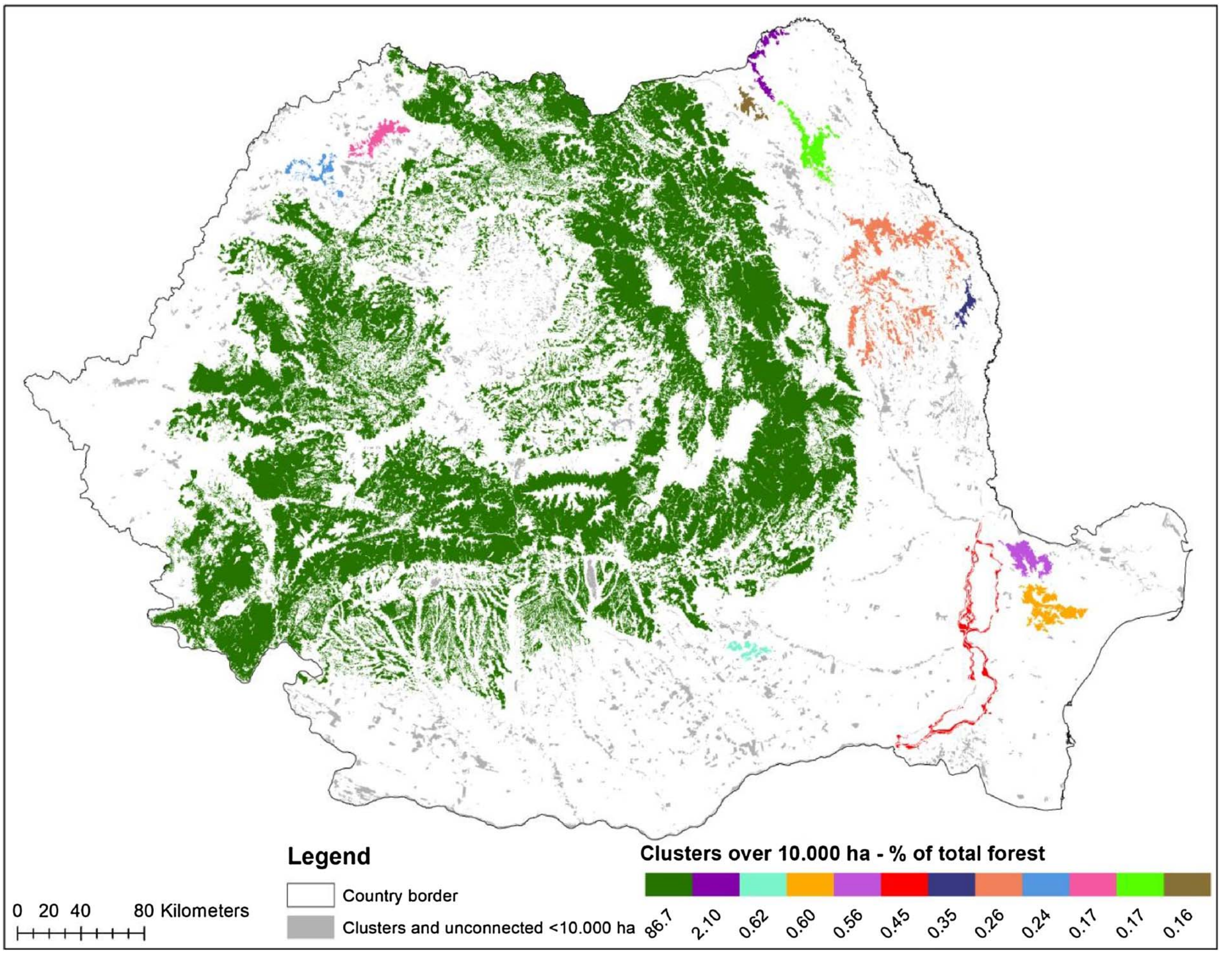

Fig. 4. Clusters resulting from the connectivity analysis for a threshold distance of 1 km.

3.3. Connectivity strength

All four classes of connectivity strength were detected (Table 4). Out of the total area of forestland for 87,4% (6.246.175,41 ha) the connectivity was strong. Even more, out of the forests with a strong connection, 96% came from HCs (i.e. areas large enough to ensure perpetuation and self-regulation of forest ecosystems), even though their number was low (894 polygons, 11,7% of the total). Unconnected polygons, which represent only 1,3% of the total area at the national level (943 polygons of 3,2 to 2.364 ha) belonged to all three size classes. Even though the majority of the area (66,4%–67.796 ha) in this case came from HIs (i.e. areas from 15 to 499 ha), almost 33% were HCs

Table 4
Distribution of size categories on connectivity strength classes. (HC – habitat continuum; HI – habitat islands; IN – interconnectivity nodes).

Statistics	*CONNECTIVITY STRENGTH*											
	Strong				*Medium*			*Weak*	*Not Connected*			
	TOTAL	*per category:*			*TOTAL*	*per category:*		*TOTAL (only INs)*	*TOTAL*	*per category:*		
		HC	*HI*	*IN*		*HI*	*IN*			*HC*	*HI*	*IN*
AREA (ha)												
Mean	773,42	6749,49	79,04	6,88	52,31	70,92	6,71	8,11	108,27	900,70	86,47	7,98
Std Err	174,77	1565,30	2,05	0,04	0,64	0,83	0,05	0,05	6,64	74,79	3,34	0,34
Median	10,10	1045,25	36,31	5,98	25,04	37,20	5,81	7,65	41,27	746,81	47,98	6,76
Std Dev	15706,32	46802,32	97,21	3,13	75,95	83,21	3,01	3,42	203,83	454,95	93,54	3,78
Min	3,14	500,76	15,01	3,14	3,14	15,01	3,14	3,14	3,20	516,34	15,01	3,20
Max	890965,74	890965,74	496,97	14,99	499,87	499,87	14,98	15,00	2364,63	2364,63	485,93	14,98
Tot Area	6246175,41	6034042,77	178241,54	33891,10	747143,15	719366,53	27776,62	46790,14	102095,17	33325,88	67796,02	973,27
% area	100	96,60	2,86	0,54	100	96,28	3,72	100	100	32,65	66,40	0,95
COUNT (no. of patches)												
No. of polygon.	8076	894	2255	4927	14283	10143	4140	5769	943	37	784	122
% no.	100	11,07	27,92	61,01	100	71,01	28,99	100	100	3,92	83,14	12,94
Proportion of total habitat area (i.e. 7.142.203,87 ha) and total count of habitat patches (i.e. 29.071)												
% habitat area	87,4				10,5			0,7	1,4			
% polygon. count	27,8				49,1			19,9	3,2			

Table 5
Distribution of forest area on size categories and connectivity quality classes. (HC – habitat continuum; HI – habitat islands; IN – interconnectivity nodes).

SIZE CATEGORY	CONNECTIVITY QUALITY					
	HIGH		MEDIUM		LOW	
	area (ha)	%	area (ha)	%	area (ha)	%
HC	6.060.374,0	95,7	6.994,6	0,1	0,0	0,0
HI	233.293,4	3,7	697.172,9	72,8	34.937,8	17,6
IN	38.306,3	0,6	21.888,8	27,1	49.236,0	82,4
TOTAL	6.331.973,7	100	726.056,3	100	84.173,8	100
Proportion of each quality category out of the total habitat area (7.142.203,87 ha)						
%	88,6		10,2		1,2	

(larger areas, over 500 ha) which are less affected by isolation as intrapatch connectivity is ensured. When the polygons with weak connectivity (which are only INs – i.e. individual polygons under 15 ha) were added to the unconnected ones, the resulting area (weak connection and no-connection) made up only 2% of the total forestland of the country.

3.4. Connectivity quality

The distribution of forest patch size categories (in terms of their cumulated area and number) in connectivity quality classes is presented in Tables 5 and 6. Similar to the situation on size classes and connectivity strength, the quality was high for most of the area (88,6%). Therefore, despite the relatively low number of patches included in this connectivity quality class (compensated by the size of patches and clusters), the present context shows very good chances for long term survival of the forest tree populations.

Regarding the connectivity quality for each size category (Tables 2 and 3 from the Appendix in Supplementary material), for HCs, almost all patches (98,7% of them, covering 99,9% of the category) had high quality connectivity and none of them were in the low-quality class. While this might not be surprising, the situation for the intermediate size patches (HIs) was rather different, most of them (66,7% of the total, covering 72,7% of the category) being in the medium quality class. In the case of the INs, the distribution between the high quality and low quality was not very different (high quality – 37,2% in terms of numbers and 35% in terms of cumulated area; low quality – 40,9% in terms of numbers and 45% in terms of cumulated area) showing that many of these small patches were connected to larger ones or larger clusters.

3.5. Distribution and connectivity for main forest tree species

The distribution for the main forest tree species in the forested landscapes show a good connectivity in terms of size class (large proportion included in HCs showed good intrapatch connectivity) and in terms of connectivity strength and quality (stronger and higher quality connections show good interpatch connectivity) (Table 7). The values were higher for mountainous species (beech and spruce) and tended to decrease for species located in the lowlands (oak species).

Table 6
Distribution of forest patches on size categories and connectivity quality classes. (HC – habitat continuum; HI – habitat islands; IN – interconnectivity nodes).

SIZE CATEGORY	CONNECTIVITY QUALITY					
	HIGH		MEDIUM		LOW	
	no	%	no	%	no	%
HC	919	9,6	12	0,1	0	0,0
HI	3086	32,2	8788	72,8	1308	17,6
IN	5566	58,2	3271	27,1	6121	82,4
TOTAL	9.571	100	12.071	100	7.429	100
Proportion of each quality category out of the total count of habitat patches (29.071)						
%	32,9		41,5		25,6	

For a spatially visual analysis of the connectivity quality, maps with the distribution of the natural range of the main forest tree species were produced (Fig. 5). They were derived from the connectivity quality layer which was transferred into a 5 × 5 km grid. Cells were assigned to the quality class which represented the majority of the area inside the cell.

Fig. 5 and Table 7 show that the ranges of mountainous species (European beech and Norway spruce) were located in areas with generally better connectivity quality than those located in the lowlands (oaks) where human induced fragmentation was higher as mentioned in the introduction. Between the first two species, beech had a larger range located mostly in areas with high quality and strong connectivity, while spruce showed a smaller but more compact range (showing also high quality and strong connectivity) with an isolated but very large island (good intrapatch connectivity) in the Western Carpathians. Sessile oak had good quality connectivity around the mountainous range with two routes of connectivity, in the western part and in the middle of the Southern Carpathians (on the Olt River valley). The south-eastern island disconnected from the rest of the range had a large area (good connectivity quality). Turkey and Italian oaks had two major range areas, dominated by good quality connectivity, in the west and south of the country, with a thin line of potential connectivity in between, along the Danube River. Pedunculate oak, as expected, had a large distribution across the country. However, the range was fragmented with a larger proportion of medium and low-quality connectivity areas.

4. Discussion

4.1. Forest connectivity

Nature conservation in Europe has changed from site protection to the conservation of ecological networks, including the wider landscape, understanding the importance of connectivity and the inefficiency of conservation based solely on protected areas (Jongman and Pungetti, 2004). Moreover, recent research on climate change effects (Hannah et al., 2007) showed that in a changing climate the existing protected areas are not ensuring conditions for species migration and therefore for their survival. Therefore, an integrated landscape mosaic approach to conservation is more efficient than the old system based only on different categories of protected areas (which cannot ensure the conservation targets by themselves) (Bennett, 2003). Such an approach seeks creation of networks of habitat patches including both protected and unprotected lands that together provide a much better system for the conservation of biodiversity. In this context, the analysis carried out at EU level on the Natura 2000 connectivity (Estreguil et al., 2013) showed that Romania, with a total of 404 sites covering 22,6% of the national territory, when emphasis is put on site size, is among the member states with well-connected Natura 2000 networks. However,

Table 7
Distribution for the main forest tree species on size categories, connectivity strength and connectivity quality classes. (HC – habitat continuum; HI – habitat islands; IN – interconnectivity nodes).

	Picea abies		*Fagus sylvatica*		*Quercus petraea*		*Quercus robur*		*Q. frainetto and Q. cerris*	
Range area (ha)	1.772.697,23		4.004.088,51		2.006.732,10		323.649,52		623.487,51	
Size categories	**area (ha)**	**(%)**	**area (ha)**	**(%)**	**area (ha)**	**(%)**	**area (ha)**	**(%)**	**area (ha)**	**(%)**
HC	1.728.739,19	97,5	3.697.525,00	92,4	1.616.171,64	80,6	204.833,42	63,3	447.418,39	71,8
HI	37.498,83	2,1	269.310,48	6,7	359.847,40	17,9	114.818,87	35,5	161.520,10	25,9
IN	6.459,20	0,4	37.253,02	0,9	30.713,05	1,5	3.997,24	1,2	14.549,02	2,3
Connectivity Quality	**area (ha)**	**(%)**	**area (ha)**	**(%)**	**area (ha)**	**(%)**	**area (ha)**	**(%)**	**area (ha)**	**(%)**
High	1.740.334,13	98,2	3.796.808,64	94,8	1.727.305,39	86,1	222.083,07	68,6	499.527,20	80,1
Medium	28.557,42	1,6	188.756,18	4,7	261.147,75	13,0	95.139,06	29,4	115.747,85	18,6
Low	3.805,67	0,2	18.523,68	0,5	18.278,95	0,9	6.427,39	2,0	8.212,46	1,3
Connectivity strength	**area (ha)**	**(%)**	**area (ha)**	**(%)**	**area (ha)**	**(%)**	**area (ha)**	**(%)**	**area (ha)**	**(%)**
Strong	1.733.082,37	97,8	3.767.930,64	94,1	1.713.010,28	85,4	217.566,56	67,2	472.285,02	75,8
Medium	37.659,09	2,1	223.156,86	5,6	272.768,85	13,6	78.170,74	24,2	117.843,75	18,9
Weak	1.937,76	0,1	11.854,18	0,3	10.555,36	0,5	2.257,68	0,7	5.809,97	0,9
Unconnected	18,01	0,0	1.146,83	0,0	10.397,61	0,5	25.654,54	7,9	27.548,77	4,4

when site size is ignored, and emphasis is placed only on inter-site distances (for a dispersal distance of 500 m) and inter-site landscape resistance along least cost paths connecting sites, Romania falls out of the short list at the EU level (being ranked 11th out of 26). Our results showed a much better connectivity for forest vegetation at country level, but for a larger limit of dispersal distance (1000 m) and without taking into account for landscape resistance (which is much less reduced in this study due to the high ability to travel of seeds and especially pollen of the subject species − forest trees). Taking into account these differences between the two studies, the conclusions do not necessarily contradict each other.

The empirical evidence on high species diversity on managed lands (outside of the existing protected areas), especially the high abundance of species threatened or extinct in other parts of Europe (e.g. large carnivores, birds, bats, invertebrates and amphibians) must be linked to the past and present management of the land and land use policies. One particular feature is the state control over forestry activities on all lands regardless of size and ownership. In addition, the low intensity (extensive) forest management, especially tending operations, allows for the participation of many species (including the early succession species) in contrast to the very intensive management carried out in Western Europe (e.g. Germany – where poorly formed trees and non-commercial species are eliminated in the early stand development stages) (Schulze et al., 2014). Although the system is not really 'cut and leave' as pictured by Schulze et al., the low intensity silvicultural works (most of the times carried out manually) allow forests to attain a high diversity in terms of structure and species composition, providing a quite natural succession of plant species and therefore offering habitat continuity for animals (Schulze et al., 2014). Such conditions were provided for many decades at very large scales not only inside protected areas but across the entire forested landscapes of the country. This context of connectivity across the country provides good conditions for species movements in the context of climatic changes as well. The recent disturbances resulting from the land restitution process in a context of inefficient state control and lack of financial incentives for sustainable management combined with immediate economic benefits of small owners, have triggered changes in habitat conditions. However, the 300.000 ha illegally harvested are not in one location and, more importantly, the land use has not changed. The forests are gradually (and most of the time naturally) restoring in a natural succession process, providing habitat and connectivity again. Even in the case of forest vegetation cleared for reclaiming pastures, in many cases the land has been abandoned after harvesting and natural succession is bringing the forest trees back.

The results presented here differ from those carried out at the European level by Estreguil et al. (2012), in our case, the results reporting a larger connectivity at the country level. However, our analysis was carried out at the national level while ignoring EU nomenclature of territorial units for statistics (NUTS) region boundaries, and therefore recorded all connected areas regardless of their spatial administrative location. Therefore, all patches closer than 1 km (regardless of their spatial position – inside or outside a certain NUTS region) were recorded as connected. As a result, in the NUTS regions where connectivity was generally low but were adjacent to the Carpathians (the area with the largest connectivity), the average per region was low while at least parts of the forested patches were connected to others outside the region (and their connection could be strong). Our analysis detected the connectivity missed by using administrative boundaries, averaging across the NUTS region and by using 25 × 25 km squares. Moreover, we have considered in our analysis all forests, including the recently regenerated areas (like clear-cuts), not included in the analysis carried out by Estreguil et al. in 2012. Regarding this methodology difference, the increase in connectivity detected by Estreguil et al. (2012) between 1990 and 2006 due to a gain in forest areas we assume it is rather due to the young forests established after the regeneration cuttings (not included in the analysis in 1990) and not a true increase in the forestland of the country. This assumption is also sustained by the fact that the area of the forestland has been confirmed to be quite stable in the last years (INCDS Marin Dracea, 2016).

The stepwise increase in buffer widths showed that areas in the north-west and central parts connect to the main cluster (Carpathians) for shorter distances (implying lower efforts), while the north-eastern, southern and south-eastern parts became connected to this cluster only for larger buffer distances (1500 m for the N-E, and 2000 m for other two) implying higher efforts. For these cases, the locations where potential connectivity bridges were identified were usually located close to or along rivers starting from the Carpathians and flowing towards Danube River in the south and Siret River in the east. In general, the existing waters and forests policies are favourable to connectivity efforts along rivers. Water legislation (Romanian Parliament, 1996) requires a protection zone along rivers and therefore promotes the presence of vegetation and careful management of these areas. The Forestry Code (Romanian Parliament, 2008) and the Forestry technical norms (Romanian Government, 2000a) require that forested areas (along rivers) should be managed to ensure water quality maintenance, protection of riverbanks and flood control (probably one of the main reasons for their perpetuation in these places). A potential conflict exists with the policies and legislation on agriculture. Grasslands Law (Romanian Government, 2013) generally forbids land use change on such lands (such as from grassland to forest use). The exceptions mentioned in the document do not clearly address the connectivity issue and therefore hinder afforestation efforts for increasing forest connectivity. Moreover, recent EU payments for agriculture (Romanian Government, 2015) were offered per area units (hectares of land)

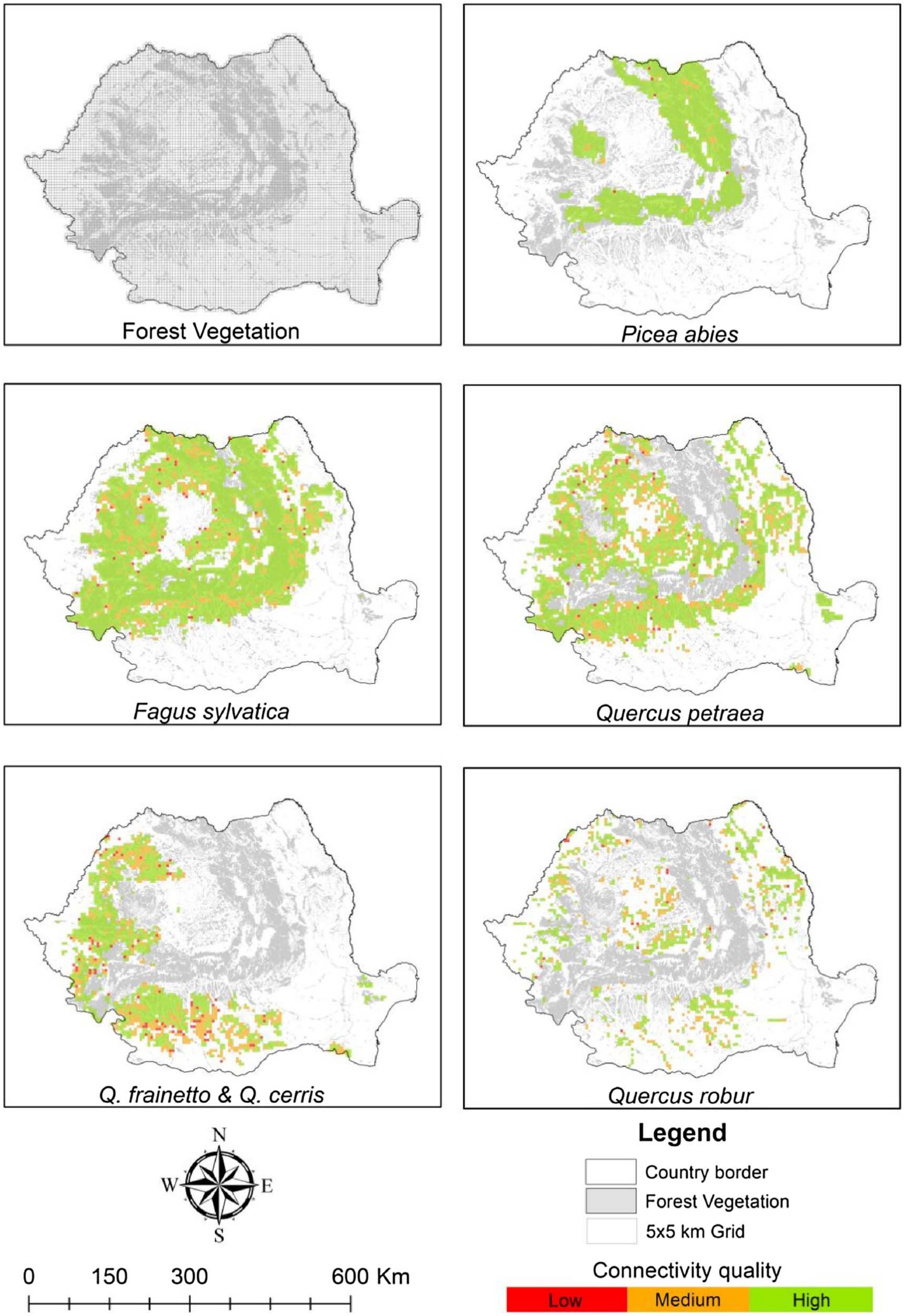

Fig. 5. Distribution of main forest tree species in different connectivity quality classes.

indirectly stimulating farmers to clear the wooden vegetation from their agricultural lands to increase the area eligible for payments (area used for agricultural purposes; area covered by tree canopies not being eligible) and therefore, undermine the forest connectivity efforts. It is important to mention that forests along rivers (including riparian forests) also provide specific habitat for many plant and animal species and also 'least-cost-paths' for the connectivity of animal species (Johansson et al., 1996; Rudnick et al., 2012), many of them being already included for such reasons in Natura 2000 sites (Iojă et al., 2010; Opermanis et al., 2012). As a result, increasing the connectivity in such areas would have multiple benefits not only for biodiversity but also for other environmental objectives. Therefore, harmonisation of the

existing policy provisions is needed to prioritise connectivity as a goal and ensure the legal framework for acquiring this goal at least in important areas. In order to be efficient such legal framework must also include clear provisions related to incentives or compensations for private ownership.

4.2. Connectivity for main forest tree species

In terms of main forest tree species distribution across the country, our results match the general distribution of forests at the national level, with higher levels of disturbance and fragmentation in the lowlands compared to the mountainous areas of the Carpathians. European beech and Norway spruce (the most common forest tree species in the country, located mostly at higher elevations) were found in large size patches (97,5% of the spruce range was in HCs and 92,4% for beech, respectively) showing a very good intrapatch connectivity but also very good interpatch connectivity both in terms of strength (connection was strong for 97,8% of the spruce range and 94,1% for beech) and quality (connection quality was high for 98,2% of the spruce range and 94,8% for beech). These indicators decreased for the oak species, especially for those located at the lowest altitudes (e.g. pedunculate oak – *Q. robur*). However, the three indicators (size category, connectivity strength and quality) show a relatively good connectivity for these species as well. For pedunculate oak, which showed the most fragmented range, top classes for all three indicators were above 60%. It is worth mentioning that, as the distribution map was built based on forest types including the subject species (therefore including pure but also mixed species stands), our analysis was carried out on forest patches which could include other species as well. Therefore, the physical distance between individual trees or patches of trees from a certain species could be over the set limit (1 km). However, the presence of a forest patch in the favourable range of the species should offer good chances for connectivity in the future even at present as the 1 km distance is quite low compared to the travel ability of seeds and especially pollen. It should also be stressed that areas of habitat were separated by natural barriers in many cases and not due to human disturbances. For example, the Norway spruce island from the Western Carpathians is isolated by the lowlands between these mountains and the Southern Carpathians. The sessile oak range was fragmented by the Eastern Carpathians with altitudes too high for this species. Nevertheless, the isolation in other cases, e.g. the oaks islands from the south-eastern part of the country, is a result of human impact (land use change for agriculture and other land uses).

5. Conclusions

Despite the large number of forest fragments making up the 7.142.203,87 ha of forest vegetation in Romania (29.071 patches, or probably even more as those under 25 ha were not included in the initial dataset), a large proportion of them had areas large enough to ensure the long-term survival of forest tree populations (85% were HCs). Even more, for a dispersal distance of only 1 km (considered conservative according to the latest research in terms of pollen dispersal), most of the forest fragments were connected (98.6% of the total area) and have a strong (87.5% of the total area) and high quality (88.7% of the total area) connection. The top 12 clusters resulting from the connectivity made up 92,4% of the total forest area at the country level, the largest one, formed around the Carpathians, covering 6.103.601,57 ha (85,5% from the total forest area). The real connectivity could be even larger due to patches smaller than 25 ha (not included in the initial dataset) and areas excluded during the minimum width (edge) analysis. There are also good chances for further improving the present connectivity due to numerous unconnected patches which are interspersed with the existing clusters (reducing gaps among them and increasing chances for connectivity in the future). Moreover, the areas identified as potential connectivity routes in this research (Figs. 1–6 from the Appendix in Supplementary material) could be useful for future efforts to further improve the connectivity and establish a large network of forest patches providing viable conditions for species perpetuation at the national scale.

For the most common forest tree species, the distribution provides good connectivity (either through connected patches as interpatch connectivity or inside large patches as intrapatch connectivity) showing that the technical guidelines enforcing the maintenance and restoration (if necessary) of the natural forest type has succeeded to produce a balanced spatial distribution for the main species in their range. The lower connectivity in the lowlands is mainly due to land-use changes in the past for agriculture and other goals (infrastructure, urban and rural development).

Traditional forestry, according to the present policies and guidelines (rooted in the past century and maintained relatively unchanged) ensures not only sustainable management from the point of view of the timber production but also from the point of view of biological diversity. Heavy restrictions on land use changes in the case of forests have safeguarded the matrix of well-connected patches across the country (inter-patch connectivity) and also avoided the reduction in size of individual forest patches (promoting a good intra-patch connectivity). Together with legal requirements on the maintenance of natural forest types (enforcing presence of naturally occurring species), the length of cutting cycles (allowing for the presence of mature trees, producing propagules for decades before being removed), promotion of natural regeneration (using the local genetic source) and the balanced age class structure of ownership (ensuring presence of mature stands in different parts of the forest, as sources for dispersal and genetic exchange) are drivers not only for the high connectivity identified here for forests (in terms of trees) but most probably for biodiversity conservation creating the habitat conditions (the growing space) needed by most forest-dwelling species. Enforced by the state on all forests regardless of ownership (despite the fact that they reduce economic efficiency), the regulations ensure the growing space conditions across the forested landscapes, outside of the existing protected areas, providing the key support for the high biodiversity present at very large scales in Romania. Therefore, the continuous enforcement of key rules would perpetuate the actual forest area and its connectivity with all subsequent advantages for humans and wildlife. However, although the control capacity of the state over forest management has improved in recent years, the lack of financial incentives to compensate the losses incurred due to the imposed measures and therefore to support a sustainable management of private forests (especially in the case of small ownerships – less than 10 ha) still poses an important threat to the maintenance of a favourable context for connectivity and conservation.

Agricultural policies should be adjusted to specifically address the needs for connectivity as well. However, as private ownership today covers a large share of the forestland and most of the agricultural lands, sound land use policies must include incentives for owners to continue managing their resources for both production and biodiversity. Such incentives are essential for ensuring the diverse habitat conditions which provide growing space to the highly diverse flora and fauna at present.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.landusepol.2018.02.028.

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